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U.S. Department of Energy's Site Screening, Site Selection, and Initial Characterization for Storage of CO₂ in Deep Geological Formations

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Abstract

The U.S. Department of Energy (DOE) is the lead Federal agency for the development and deployment of carbon sequestration technologies. As part of its mission to facilitate technology transfer and develop guidelines from lessons learned, DOE is developing a series of best practice manuals (BPMs) for carbon capture and storage (CCS). The “Site Screening, Site Selection, and Initial Characterization for Storage of CO₂ in Deep Geological Formations” BPM is a compilation of best practices and includes flowchart diagrams illustrating the general decision making process for Site Screening, Site Selection, and Initial Characterization. The BPM integrates the knowledge gained from various programmatic efforts, with particular emphasis on the Characterization Phase through pilot-scale CO₂ injection testing of the Validation Phase of the Regional Carbon Sequestration Partnership (RCSP) Initiative. Key geologic and surface elements that suitable candidate storage sites should possess are identified, along with example Site Screening, Site Selection, and Initial Characterization protocols for large-scale geologic storage projects located across diverse geologic and regional settings. This manual has been written as a working document, establishing a framework and methodology for proper site selection for CO₂ geologic storage. This will be useful for future CO₂ emitters, transporters, and storage providers. It will also be of use in informing local, regional, state, and national governmental agencies of best practices in proper sequestration site selection. Furthermore, it will educate the inquisitive general public on options and processes for geologic CO₂ storage. In addition to providing best practices,

the manual presents a geologic storage resource and capacity classification system. The system provides a “standard” to communicate storage and capacity estimates, uncertainty and project development risk, data guidelines and analyses for adequate site characterization, and guidelines for reporting estimates within the classification based on each project’s status.

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The goal of the U.S. Department of Energy’s (DOE’s) Sequestration Program is to demonstrate that carbon dioxide (CO₂) can be successfully and securely stored over extended periods of time in a manner that is compliant with the best engineering and geological practices; Federal, State, and local regulations; and the best interests of local and regional stakeholders. This will directly link the national interest in reducing greenhouse gases with regional and local economic, environmental, and social interests. As part of its mission to facilitate technology transfer and develop guidelines from lessons learned, the DOE is developing a series of best practice manuals (BPMs) for carbon capture and storage (CCS). These BPMs will integrate work from numerous programmatic efforts on a variety of technical and non-technical subject matters relevant to the commercial deployment of CCS, including monitoring, verification, and accounting (MVA); public outreach and education; simulation and risk assessment; well construction and closure; terrestrial sequestration; and site characterization. This paper is based on the Site Screening, Site Selection, and Initial Characterization (SSSIC) for Storage of CO₂ in Deep Geologic Formations BPM, a compilation of best practices and flowchart diagrams with guidelines illustrating the general decision making process for evaluating potential geologic storage sites [1].

The SSSIC BPM draws significantly upon the knowledge and experience gained from the DOE’s Regional Carbon Sequestration Partnership (RCSP) Initiative, comprised of seven regional partnerships divided throughout the United States who are developing the foundation for the demonstration and commercialization of carbon sequestration technologies [2]. The RCSP Initiative is being implemented in three phases: (1) Characterization Phase (2003 – 2005), (2) Validation Phase (2005 – 2011), and (3) Development Phase (2008 – 2018). During the Characterization Phase, the RCSPs characterized the potential geologic storage opportunities within each of their respective regions. The knowledge gained allowed the RCSPs to implement a series of small-scale geologic CO₂ storage projects in a variety of geologic and geographic settings during the Validation Phase.

As reported in the DOE’s 2008 Carbon Sequestration Atlas (Atlas II), Prospective Storage Resource estimates in the United States and Canada range from 3,600- 12,600 billion metric tons, representing hundreds of potential years of storage [3]. Although there is large potential for storing CO₂, the process of identifying suitable sites with adequate storage involves methodical and careful analysis of the technical and non-technical features to characterize these sites for long-term safe storage. The process described in the SSSIC BPM builds upon the experiences of the RCSP Initiative and integrates those into a geologic storage classification framework based upon the best practices of the petroleum industry. The framework will help to provide a roadmap for standard expectations for data collection and analyses by classifying projects to a specific project-status that could be compared throughout the world.

The process of identifying suitable CO₂ storage sites is analogous in many ways to the exploration for, and development of, oil and gas accumulations. The petroleum industry has developed a resource classification that has evolved over many decades to meet industry and regulatory requirements, many of which are essentially the same as those evolving for the emerging CCS industry. A proposed Geologic Storage Resource Classification framework, adapted from the SPE/WPC/AAPG/SPEE Resource Classification System, Petroleum Resources Management System (PRMS) is shown in Figure 1[4]. The proposed framework is divided into three Phases that correspond to resource classes: Exploration Phase (Prospective Storage Resources), Site Characterization Phase (Contingent Storage Resources) and

Implementation Phase (Storage Capacity). Each resource class is then further divided into project status sub-classes to show project maturity [4] [5]. The primary focus of the BPM is on the Exploration Phase associated with the Prospective Storage Resources class. The Exploration Phase is further divided into three project status sub-classes that undergo a set of comprehensive evaluation processes for classification: Potential Sub-Regions (Site Screening Process), Selected Areas (Site Selection Process), and Qualified Site (Initial Characterization Process). Each of the evaluation processes includes a series of components with identified elements to be analyzed.

Petroleum Industry		CO ₂ Geological Storage	
Reserves		Implementation	Storage Capacity
On Production			Active Injection
Approved for Development			Approved for Development
Justified for Development			Justified for Development
Contingent Resources		Site Characterization	Contingent Storage Resources
Development Pending			Development Pending
Development Unclassified or On Hold			Development Unclassified or On Hold
Development Not Viable			Development Not Viable
Prospective Resources		Exploration	Prospective Storage Resources
Prospect			Qualified Site(s)
Lead			Selected Areas
Play			Potential Sub-Regions

Exploration	Prospective Storage Resources	
	Project Sub-class	Evaluation Process
	Qualified Site(s)	Initial Characterization
	Selected Areas	Site Selection
	Potential Sub-Regions	Site Screening

Figure 1. Comparison of Petroleum and CO₂ Storage Classification Frameworks, adapted from the SPE/WPC/AAPG/SPEE Resource Classification System. (© 2007 Society of Petroleum Engineers, Petroleum Resources Management System.) [4].

With a standardized classification system, project status could be compared consistently between projects throughout the United States and internationally with a common understanding of the level of detail in the evaluations completed to achieve each project status. Due to the infancy of carbon sequestration, there are some caveats to proposing this classification system at this time. The structural foundation can be developed into classes and sub-classes with general definitions and the Exploration Phase can be fully defined. However, completing the definitions and constructing guidelines for Site Characterization and Implementation Phases is premature at this time. This further level of detail will evolve with experience as commerciality is further defined by the commodity price of CO₂, value for stored CO₂ in pore space, and established “cost of doing business” expenses for power plant operators and other industries involved in CCS.

The characterization process described in the SSSIC BPM demonstrates a systematic approach for selecting a suitable site. The process pares down larger Potential Sub-Regions in a basin through the Site Screening Process, identifies Selected Areas within the Potential Sub-Region through the Site Selection Process, and determines Qualified Sites through the Initial Characterization Process. In order to better

understand the relationship between the framework project sub-classes and evaluation processes, a conceptual representation is shown in Figure 2.

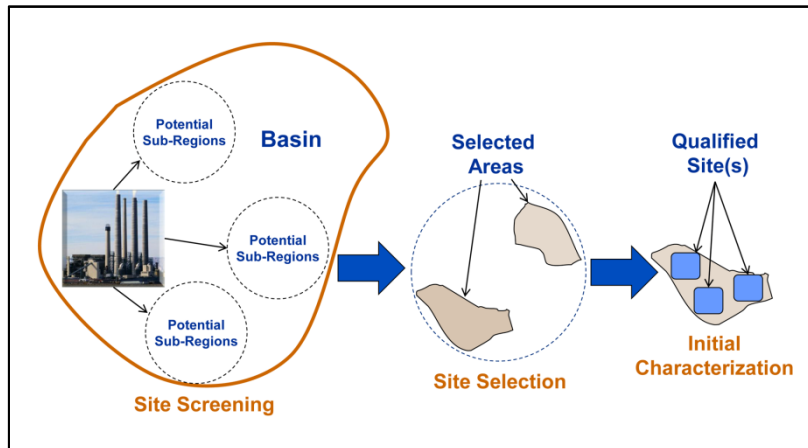


Figure 2. Conceptual representation of processes to identify “Qualified” geologic storage sites through the Exploration Phase

As shown from this diagram, the Exploration Phase can be extensive and require large data sets to be analyzed by various technical and non-technical teams. Therefore, prior to initiating the Exploration Phase a project developer should perform an analysis, to plan and manage the projects needs, organization, management structure, and available resources. This analysis is called a Project Analysis and is performed on the Project Definition component. During Project Analysis, the developer creates a detailed plan based on analysis of six elements within the Project Definition Component: (i) Scope; (ii) CO₂ Strategy; (iii) Evaluation Criteria; (iv) Resources; (v) Schedule; and (vi) Risk Assessment. During this analysis the overall project, from Exploration to Implementation is envisioned and delineated; however, there is an emphasis on the three evaluation stages of Exploration: Site Screening, Site Selection, and Initial Characterization. Project Definition should involve outlining a plan for future steps and create a framework for addressing contingencies. The initial plan should be revisited at each evaluation stage to incorporate the results. The SSSIC BPM provides guidelines for carrying out each of the steps involved during the Project Analysis [1].

The Exploration Phase consists of three sets of evaluations: Site Screening, Site Selection, and Initial Characterization. At each evaluation stage, the Prospective Storage Resources are calculated and refined incorporating new data and analysis results as the project moves toward the Site Characterization Phase—Contingent Storage Resources. The purpose of the Site Screening stage is to evaluate sub-regional basinal data sets and assess storage potential within a defined sub-region. This stage utilizes primarily existing data and resources for this assessment and Prospective Storage Resources calculations. The Site Screening evaluation performed on Potential Sub-Regions, analogous to the maturation of a petroleum project from “play” to “lead” includes three components for analysis: (1) Regional Geologic Data; (2) Regional Proximity Data; and (3) Social Data. Elements within these components can be evaluated simultaneously while working towards answering the questions posed at the decision gates: “no” responses move the analysis to a new Potential Sub-Region, and a “yes” response leads to inclusion on the list of Selected Areas to be ranked and further evaluated during Site Selection. Prior to initiating each component analysis, a multi-disciplinary team should be assembled and define the analysis to be conducted incorporating each of the elements. When defining the analysis, the team should consider scope, evaluation criteria, resources, and schedule. Again, this process should be conducted for each of the components within the evaluation stage to ensure the project needs and resources are adequately planned for in order to properly complete all the analyses. The Site Screening evaluation will identify those Potential Sub-Regions with the highest potential for storage and help eliminate from consideration those that are less preferable. The most promising areas within the Potential Sub-Regions would then proceed to the second stage of the

Exploration Phase and be classified as Selected Areas. Figure 3 provides a more detailed overview of the entire Site Screening evaluation and Table 1 provides recommended guidelines for the types of data and analyses necessary to complete the Site Screening evaluation.

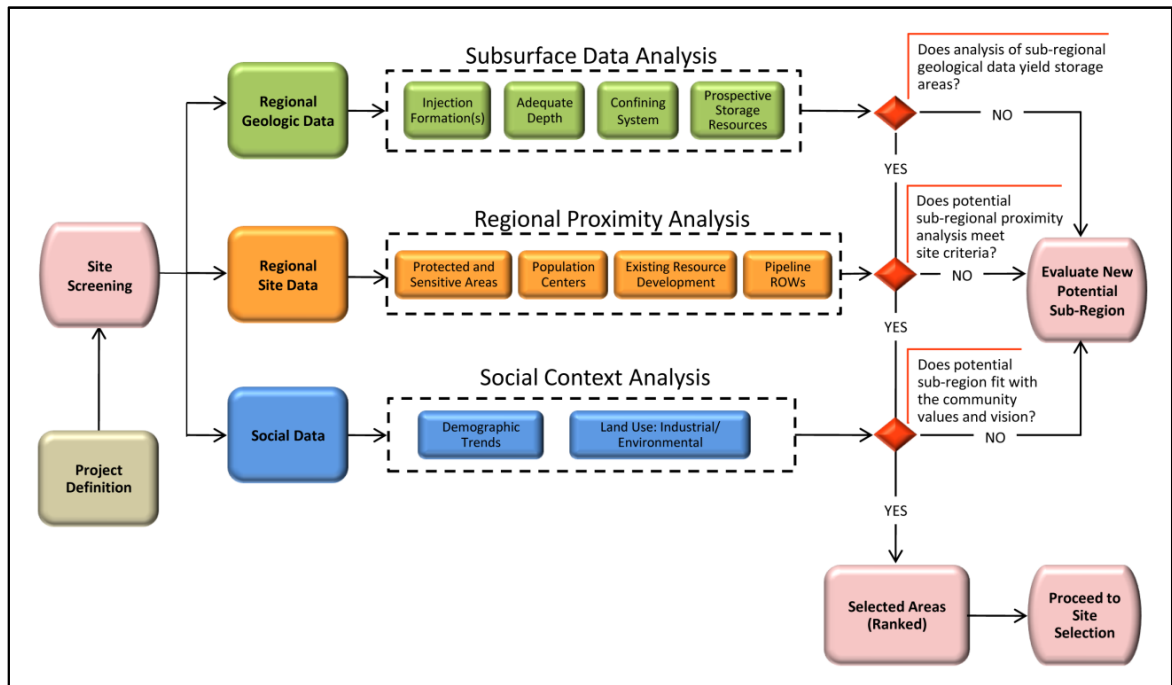


Figure 3. The process flowchart for Site Screening evaluation on Potential Sub-Regions.

COMPONENT		ELEMENT	GUIDELINES FOR SITE SCREENING
Regional Geologic Data	Subsurface Data Analysis	Injection Formation(s)	Identify regional and sub-regional injection formation types. Utilize readily accessible data from public sources (e.g., state geological surveys, NATCARB, the Regional Sequestration Partnerships, published and open-file literature, academic sources) or acquired from private firms. Data gathered should include regional lithology maps, injection zone data (thickness, porosity, permeability), structural maps, information about structure closure and features that might compartmentalize the reservoir such as stratigraphic pinch outs, regional type logs, offset logs, petrophysical data, and regional seismicity maps.
		Adequate Depth	Assessment of minimum depth of the injection zone to protect USDWs is required; in addition depths greater than 800 m generally indicate CO ₂ will be in a supercritical state and may be more cost-effectively stored. Shallow depths (generally < 800 m) may add to the risk profile because (1) CO ₂ could be in gas phase and (2) the injection zone may be closer to USDW.
		Confining System	Candidate injection zones should be overlain by confining system comprised of one or more thick and impermeable confining zones of sufficient lateral extent to cover the projected aerial extent of the injected CO ₂ . Confining systems can be identified on a regional basis from the same types of information used to identify injection formations. Wells that penetrate potential confining systems should be identified and included in the risk assessment; this information can be obtained from state oil and gas regulatory agencies. Faulting and folding information that may impact confining system integrity should be mapped along with potential communication pathways. Confining system integrity may be validated by presence of nearby hydrocarbon accumulations.
		Prospective Storage Resources	Candidate CO ₂ storage formations should contain enough Prospective Storage Resources beneath a robust confining system for the volume of CO ₂ estimated during Project Definition and the displaced fluids. Prospective Storage Resources (and injectivity if permeability data is available) should be estimated at the sub-regional scale utilizing existing data (e.g., NATCARB, and state geological surveys) to populate basic numerical models.
Regional Site Data	Regional Proximity Analysis	Protected and Sensitive Areas	Identify environmentally sensitive areas using U.S. Environmental Protection Agency, U.S. Department of Interior, U.S. Forest Service and U.S. Bureau of Land Management GIS systems. Assess the potential for conflicts with siting of pipeline routes, field compressors and injection wells. In addition, evaluate potential for other surface sensitivities utilizing maps for other hazards (e.g., flood, landslide, tsunami).
		Population Centers	Identify population centers using state and federal census data. Assess the potential for conflicts with siting of carbon storage projects.
		Existing Resource Development	Identify existing resource development, including wells that penetrate the confining system, using data from state and federal oil and gas, coal, mining and UIC and natural resource management offices. Assess the potential for conflicts between siting of carbon storage projects and existing or prospective mineral leases as well the availability of complementary or competing infrastructure.
		Pipeline ROWs	Identify all pipelines and gathering lines/systems. Assess potential for conflicts in routing of pipelines to carbon storage projects as well as the potential for use or access to existing pipeline right-of-ways (ROWs). Identify other ROWs (e.g., powerlines, RR's highways) and assess potential for synergies or conflicts in siting carbon storage projects. This data can be found through commercial and government sources.
Social Data	Social Context Analysis	Demographic Trends	Describe communities above and near candidate Sub-Regions by evaluating readily available demographic data and media sources. To the extent possible, assess public perceptions of carbon storage and related issues; develop an understanding of local economic and industrial trends; and begin to identify opinion leaders.
		Land Use: Industrial and Environmental History	Describe the trends in land use, industrial development and environmental impacts in communities above or near candidate Sub-Regions by evaluating sources such as online media sites, regulatory agencies, corporate websites, local environmental group websites, and other sources. Begin to assess community sensitivities to land use and the environment.
Complete Site Screening		Selected Area	Develop a list of potential Selected Areas and rank based on criteria established in Project Definition.

Table 1. Guidelines for Site Screening evaluation for Elements within each Component.

Site Selection builds on the previous analyses conducted in Site Screening to further evaluate previously Selected Areas and develop a short list of Qualified Sites suitable for Initial Characterization. The Site Selection process augments Site Screening analyses with new, proprietary, or other purchased data to evaluate characteristics of the Selected Areas. Prior to initiating the analysis of the Selected Areas, similar to Site Screening, a multi-disciplinary team should define the analysis to be conducted at each of the components and consider scope, evaluation criteria, resources, and schedule. This stage is analogous to the second project status of an oil exploration program, called a “lead,” and evaluates five technical and non-technical components: (1) Subsurface Geologic Data; (2) Regulatory Requirements; (3) Model Data; (4) Site Data; and (5) Social Data. The SSSIC BPM provides detailed guidelines on elements to be analyzed within each of these components. As with Site Screening, these components can be evaluated

simultaneously while working towards answering the questions posed at the decision gates, which are part of the process. Accordingly, “no” responses would shift the analysis to a new Selected Area, and “yes” responses would lead to inclusion on the list of potential Qualified Sites for further ranking and evaluation. A detailed flowchart and guidelines are included in the SSSIC BPM to illustrate this process. Upon completion of the analyses, a site development plan should be outlined for each Qualified Site and used to assess their economic feasibility. Based on their economic feasibility and fit with the project goals, the project developer can establish a rank order of Qualified Sites that will be evaluated in the Initial Characterization process.

The final process of the Exploration Phase, the Initial Characterization process is analogous to processes utilized in the petroleum industry for a “Prospect.” During this evaluation stage, five technical and non-technical components should be analyzed: (1) Baseline Data, (2) Regulatory Requirements, (3) Model Data, (4) Social Data, and (5) Site Development. As with the previous two stages, prior to initiating any analyses a team should be assembled and plan the analysis to be completed at each component. Also, as with the previous two stages, analyses are evaluated and integrated simultaneously while working towards answering the questions posed at each component decision gate indicated in the Initial Characterization process chart. Accordingly, “no” responses would shift the analysis back to the list of Qualified Site(s), and “yes” responses would lead to the decision to acquire more data or elevate the site to the Site Characterization Phase. The SSSIC BPM provides both a process flow chart and detailed guidelines for the five components identified above for analysis and their respective elements [I].

Once a Qualified Site has successfully completed the Exploration Phase, it can be elevated to the Site Characterization Phase (Contingent Storage Resources). Additional analyses and large-capital investment will be necessary for the project as it moves upward through this phase of the geologic storage classification. The level of funding and detailed analyses required to advance the site to a commercial storage site is several magnitudes greater than what would be required for a site in the Exploration Phase, as a Qualified Site. Several Qualified Sites could be elevated to the Site Characterization Phase and further evaluated; however, due to the level of capital investment, this should be limited to only site(s) with commercial potential.

In conclusion, geologic storage of CO₂ is an important technology in the emerging portfolio of options to cost effectively reduce CO₂ emissions. The technical underpinning for carbon storage is found in the more than a century of experience gained in the petroleum industry and dates even further to early drilling experience for water and other resources. It is commonly agreed that the process of identifying and fully characterizing potential storage sites is fundamental to ensuring the safety and integrity of a geologic storage project. This paper, introduces the processes and guidelines from the SSSIC BPM, and draws upon the experience in the petroleum industry by adapting a classification hierarchy to classifying potential CO₂ storage resources and sites. The proposed CO₂ geologic framework consists of three phases: Exploration, Site Characterization, and Implementation. The emphasis of this paper and the associated SSIC BPM has been on the Exploration Phase and has provided a set of process flowcharts and guidelines for the thorough evaluation of potential CO₂ GS sites through the three stages of the Exploration Phase: Site Screening, Site Selection, and Initial Characterization. The Process Flowcharts and detailed Guidelines are meant to help project developers plan for and implement comprehensive site identification procedures and are not meant to be prescriptive or used for regulatory purposes. Furthermore, it will help other stakeholders to gain a more detailed understanding of the rigorous steps involved in this process. This paper and the SSSIC BPM upon which it is based, is a companion to several other carbon sequestration BPMs either recently published or under development within the DOE. Subjects for these companion documents include: Monitoring, Verification and Accounting; Simulation and Risk Assessment; Well Construction and Closure; Public Outreach and Education; and Terrestrial Sequestration.

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